

MODELING AND ANALYZING THE BER PERFORMANCE OF OFDM- MIMO SYSTEM WITH 16-QAM USING OSTBC FOR WIRELESS COMMUNICATION BASED ON MATLAB

NEHA SINGH¹, PANKAJ SHARMA² & MONICA KATHURIA³

¹M. Tech Scholar, Department of ECE, Moradabad Institute of Technology, Moradabad Uttar Pradesh, India

²Associate Professor, Department of ECE, Moradabad Institute of Technology, Moradabad, Uttar Pradesh, India

³Assistant Professor, Department of ECE, Moradabad Institute of Technology, Moradabad, Uttar Pradesh India

ABSTRACT

In this paper we have investigated the performance of OFDM-MIMO wireless system. The main objective of this paper is to introduce the basic structure of OFDM and MIMO, including the basic implementation of a MIMO model using OSTBC scheme, the effectiveness of introducing encoders and interleavers in a OFDM-MIMO system, the transmitter and receiver modeling of OFDM, and hence constructing a simple OFDM-MIMO wireless communication system in WLAN and Wi-Fi context with 16-QAM modulation composed of transmitter, channel, receiver, and so on. The system performance is simulated by using the software MATLAB. All the models are being studied for different configurations, that is, for different number of antennas at the transmitter and receiver of the communication system. The results are obtained and compared in terms of Bit Error Rate (BER), Throughput and Bandwidth.

INDEXTERMS: OFDM-MIMO, BPSK, 16-QAM, OSTBC, SNR, BER

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I. INTRODUCTION

Wireless communication being the technology's enormous contributions to mankind, is the rapidly growing segment of the communication industry, which has gained the spotlight and the imagination of the public with potentials of high-speed and high-quality and advantages like portability, flexibility and coverage over wired communication.

The chapters of wireless communication begin since 1960s, and since then from satellite transmission, radio and television broadcasting to the new universal mobile telephone, it has remodeled the way societies work and has turned into an area of research due to the confluence of several factors. First, is the enormous increase in demand for wireless connectivity. Second, the powerful progress in VLSI technology has enabled small-area and low-power implementation of complex signal processing and coding algorithm. Third, a platform created by the second generation wireless communication standards, like CDMA, to transmit voice and low volume digital data. Likewise, more advanced services are awarded to users by the third generation of wireless communications that acquires greater capacity through improved spectral efficiency[1].

Hence, wireless communication is a complex topic which can be segmented into potential applications, systems or coverage regions. Wireless applications include file transfer, paging and short messaging, Internet access, web browsing, distance learning, voice, video conferencing, entertainment, etc. Systems include cellular

telephone systems, ad hoc wireless networks, wireless LANs, wide-area wireless data systems and satellite systems. Coverage regions include in-building, city, regional, and global.

However, wireless communication faces two significant technical challenges: first is the well-known phenomenon of fading: the time variation of the channel as a result of the small-scale effect of multi-path fading and large-scale effect like path loss by distance attenuation and shadowing by obstacles. Second, is significant interference due to communication over air, between wireless transmitter and receiver.

For enhancing the data rates, providing better quality of service and higher network capacity in next generation wireless communication systems operating in complex environments promising technologies in wireless communication are introduced, like combination of OFDM and MIMO.

II. RELATED THEORIES

Wi-Fi is a wireless networking protocol that has grown rapidly in the last few years, which represents a type of Wireless Local Area Network (WLAN) protocol based on the IEEE 802.11 standards, and is used to communicate data wirelessly, within a fixed location. The rapidly evolved technology WLAN operates on the data link layer and the physical layer. The Wi-Fi system formats the data and controls it in these two layers to achieve the IEEE 802.11n standards.

2.1 OFDM

OFDM is a digital multicarrier modulation scheme which intent to meet the high data-rate demands by transforming a frequency-selective channel into parallel assembly of flat fading, non-frequency selective, narrowband channels. Thus in OFDM instead of transmitting a single stream of high-data-rate with a single carrier, it transmits number of low-rate sequences simultaneously over a number of orthogonal closely-spaced subcarriers.

The simplest block diagram of an OFDM system is as shown in Figure 1 below.

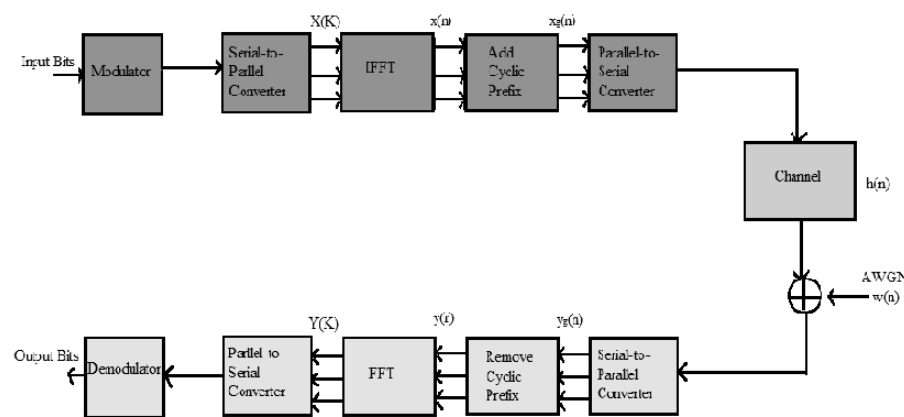


Figure 1: OFDM System Structure

The physical layer of WLAN is based on Orthogonal Frequency Division Multiplexing (OFDM) as a modulation scheme. A stream of bits generated by the random generator is used to modulate the OFDM sub-carriers by using BPSK, QPSK, 16-QAM, or 64-QAM, etc. modulation techniques. In this paper 16-QAM modulation technique is considered. The complex numbers representing 16-QAM constellation points or the complex outputs ($I+jQ$) from the modulator block are then converted into parallel form, say N sub-carriers, where each sub-carrier consists of data symbols $X(l)$ for $l = 0, 1, (N-1)$, where l is the sub-carrier number. The sub-carriers are passed through the IFFT block which is responsible for

frequency domain to time domain conversion of the signals. The time-domain OFDM signal at the output of the IFFT block can be expressed as[2]:

$$x(n) = \sum_{k=0}^{N-1} X(k) \exp(j2\pi kn/N), 0 \leq n \leq (N-1) \quad (1)$$

where n is the time-domain sample index of the OFDM signal.

After adding cyclic prefix, which serves as the guard interval, the time domain modulated OFDM symbol is again converted back to a serial stream of data which travels through the frequency selective multipath fading channel and a noisy channel with independent and identically distributed AWGN noise[3]. In this paper, we will consider AWGN[4], and frequency selective Rayleigh fading channel[5-6]. At the receiver, the signal received can be expressed as-

$$y(n) = x_g(n) * h(n) + w(n), 0 \leq n \leq (N-1) \quad (2)$$

where $w(n)$ is the independent and identically distributed AWGN sample and $h(n)$ is the discrete-time impulse response of the channel.

To obtain the original data the reverse operation is carried out at the receiver which involves serial to parallel conversion of the received data followed by the removal of cyclic prefix. The data is then passed through the FFT block to demultiplex the multi-carrier signals. The l^{th} sub-carrier FFT output in frequency domain can be expressed as-

$$Y(k) = (1/N) \sum_{n=0}^{N-1} y(n) \exp(-j2\pi kn/N) \quad (3)$$

or

$$Y(K) = X(K) * H(K) + W(K), 0 \leq l \leq (N-1) \quad (4)$$

where $W(K)$ is noise in frequency domain and $H(K)$ is the channel frequency response.

2.2. MIMO Technology

Multiple-Input Multiple-Output (MIMO) technology has become so popular because of its powerful performance enhancing capabilities. MIMO offers a number of benefits over Single-Input Single-Output (SISO) systems as high data rate, high link quality, increased robustness, more efficient management of BW and power, improved transmission reliability over a fading channel and improved throughput between the transmitter and receiver.

The advances in the range, reliability, and throughput of the WLAN technology can be brought to successful conclusion in light of IEEE 802.11n standards which take into account much enrichment as compared to other IEEE 802.11 standards.

The IEEE 802.11n standard was released in the year 2009. The enrichments of this standard includes use of OFDM and advanced signal processing at the physical layer in order to exploit multiple antennas and wider channels, and protocol enlargement at the Medium Access Control (MAC) layer in order to use the available bandwidth more efficiently. In this standard the maximum data rate of up to 600Mbps can be achieved. With this standard comes three additional features of operation on both the 2.4GHz and the 5GHz bands, the option to use 20MHz or 40MHz wide channel

(if the 40MHz wide channel capability is supported by the access point (AP)), and use of advanced antenna technology, MIMO, which support simultaneous transmission and/or reception through multiple antennas. The IEEE802.11n standard allows the use of up to 4 spatial streams, that is, extending from the “1*1” antenna configuration to “4*4” antenna configuration.

In a general form, let us consider a MIMO system with N transmit antennas and M receive antennas as shown in Figure 2, where T_N represents N^{th} transmitter antenna and R_M represents M^{th} receiver antenna. Let $x_1, x_2, \dots, x_N$ be the data transmitted simultaneously by N transmitting antennas in the same bandwidth of a radio channel. Each antenna at the receiver will receive the replicas of all the transmitted signals which are disrupted by noise in the radio channel.

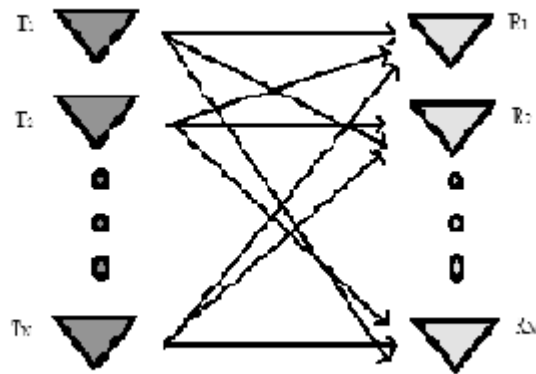


Figure 2: MIMO System Structure

Thus, the whole transmission system can be characterized by the following equation:

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_M \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1N} \\ h_{21} & h_{22} & \dots & h_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ h_{M1} & h_{M2} & \dots & h_{MN} \end{bmatrix} * \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_M \end{bmatrix} \quad (5)$$

where x_j is the signal transmitted from the j^{th} transmit antenna, y_i is the signal received by the i^{th} receive antenna, h_{ij} is the transfer function between j^{th} transmit antenna & i^{th} receive antenna and n_i is the noise on the i^{th} receive antenna. The weight coefficient h_{ij} represents the impact of the signal transmitted from the j^{th} transmit antenna on the signal strength of i^{th} receive antenna. Thus, the channel matrix H with dimension $M \times N$ can be defined as:

$$H = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1N} \\ h_{21} & h_{22} & \dots & h_{2N} \\ \vdots & \vdots & & \vdots \\ \vdots & \vdots & & \vdots \\ h_{M1} & h_{M2} & \dots & h_{MN} \end{bmatrix} \quad (6)$$

2.3. Channel Model Description

The channel tolerable delay spread in IEEE 80211.n amendment featuring OFDM and MIMO depends on the user environment. According to the measurements the outdoor environments experience maximum delay spread of up to 10 μ s.

In wireless communications, when a wave propagates from the transmitter to the receiver it encounters a number of distortions in the communication channel. First, is the presence of reflecting objects in the surrounding which causes multipath effect. The receiving antenna receives different versions of the transmitted signal at different time as the signal travels through different paths in the channel resulting in multipath fading and inter-symbol interference. Fading due to multipath spread is known as flat fading and frequency selective fading.

Second, distortion which occurs for the case when the transmitter and the receiver are in motion, at constant velocity, via to each other is called Doppler Effect. Fading due to Doppler spread is known as fast fading and slow fading.

Third, if the transmitted signal propagates through a large area between the transmitter and receiver including hills, towers, building, etc. then the attenuation in the received signal power causes fading which is grouped into path loss and shadowing.

Finally, there are noises like thermal noise in the receiver, atmospheric noise, and noise due to interference between different carriers within the channel, transmitters and systems which are independent from the transmitting signals and fading within the communication channel. These noises are modeled as Additive White Gaussian Noise (AWGN).

In our paper we have used two widely used channels AWGN channel, and frequency-selective Rayleigh fading channel.

2.3.1. AWGN Channel

The AWGN channel adds white Gaussian noise to the real or complex input signal that passes through it. The amplitude frequency response of the AWGN channel is flat with infinite bandwidth and the phase frequency response is linear for all frequencies in order that the modulated signals passes through the channel without undergoing any amplitude loss and phase distortion.

Let $s(t)$ be the transmitted signal which passes through the AWGN channel with $n(t)$ Additive White Gaussian Noise, then the received signal can be expressed as:

$$r(t) = s(t) + n(t) \quad (7)$$

2.3.2. Frequency-Selective Fading Channel

The fading effects due to multipath time delay spread results in frequency selective fading. If all the multiple

versions of the transmitted signal are affected by different amplitude gains and phase shifts then the channel is said to be a frequency selective fading channel. A frequency selective fading channel induces Inter Symbol Interference (ISI). A signal undergoes frequency selective fading if the bandwidth of the signal is greater than the bandwidth of the channel, $B_s > B_c$, and delay spread is greater than the symbol period, $\sigma_\tau > T_s$.

If we have to model multipath fading with Non-Line-of-Sight (NLOS) propagation path, the small-scale fading amplitude distribution is Rayleigh. The Probability Density Function (pdf) of Rayleigh distribution is given by:

$$p(r) = r/\sigma^2 (\exp(-r^2/2\sigma^2)), (0 \leq r \leq \infty) \quad (8)$$

and

$$p(r) = 0, (r = 0) \quad (9)$$

where σ is the rms value of the received voltage signal before envelope detection, and σ^2 is the time-average power of the received signal before envelope detection.

The received signal which passes through a combination of Rayleigh fading channel and AWGN channel can be expressed as:

$$R(n) = \sum h(n, \tau) S(n-m) + w(n) \quad (10)$$

where $w(n)$ is AWGN noise with zero mean and unit variance, $h(n)$ is the channel impulse response which can be expressed as

$$h(n) = \sum \alpha(n) e^{-j\theta(n)} \quad (11)$$

where $\alpha(n)$ and $\theta(n)$ are attenuation and phase shift for n^{th} path.

2.4. Timing Boundaries

The model of OFDM-MIMO system presented in this paper operates in the “legacy mode”. In the legacy mode, frames transmitted in the preamble are compatible with the legacy IEEE 802.11 a/g OFDM format. The frame and the timing boundaries for various fields in the legacy mode for IEEE 802.11n are as shown in Figure 3.

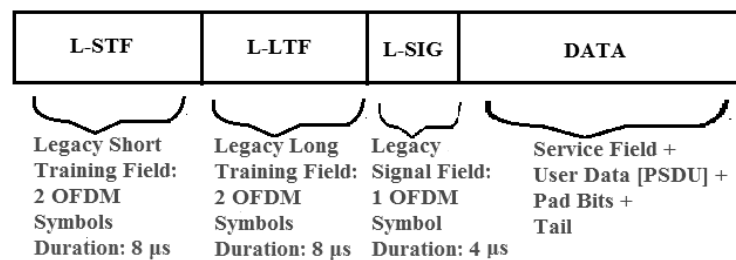


Figure 3: Timing Boundaries in Simulation Model for 802.11n Frame in “Legacy Mode”

In the legacy mode transmission over 20MHz channel, the channel is divided into 64 sub-carriers. The carrier used for the transmission of data, and the four pilots carriers used for the transmission of reference signal are inserted in sub-carrier k , where k denotes the sub-carrier number. The sub-carrier, $k=0$, being the center (DC) carrier is not used.

The first two fields L-STF and L-LTF are used as preamble for synchronization purpose. The duration of the L-STF field is 8 μ s, which consists of 10 short training symbols. The duration of each short training symbol is 0.8 μ s. Thus,

two OFDM symbols will be required to transmit the entire short training sequence as the duration of each OFDM symbol is 4 μ s. Similarly, two OFDM symbols of a total duration of 8 μ s are needed to transmit the whole long training sequence. L-SIG field is used as header which carries length and rate of data part carried in the frame. The data part is used to carry the MAC control/management frame as well as the information that need to be exchanged between the devices.

III. SIMULATION SETUP

3.1 OFDM Transceiver

A cost-effective technology can be implemented by using efficient FFT techniques at the OFDM transmitter and receiver thereby eliminating arrays of sinusoidal generators and coherent demodulation required in simultaneous data systems.

3.1.1 OFDM Transmitter

The OFDM transmitter is modeled and simulated by using SIMULINK which is an important tool of MATLAB for Multi-Domain simulation and Model-Based design. The SIMULINK model of OFDM transmitter is as shown in Figure 4.

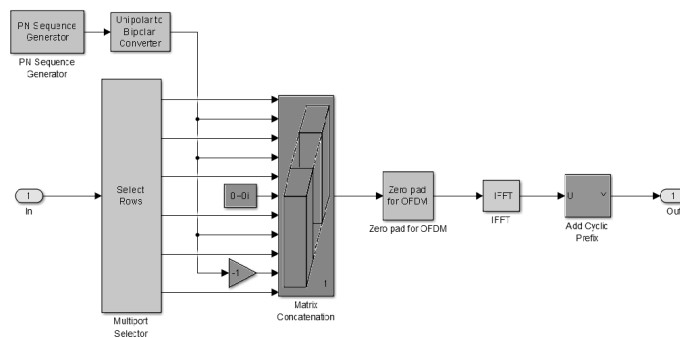


Figure 4: OFDM Transmitter Simulink Model

The multiport selector is used to select the rows of the M-by-1 input matrix. The cell array of the multiport selector is set to six cells so there are six outputs on the block which are matrices of different dimensions. The inputs to the matrix concatenation block is not only data from multiport selector but also pilot tones and a zero DC sub-carrier which are inserted between the data with a process of vertical concatenation. Thus at the output we have a matrix of dimension N-by-1, where $M < N$, that includes M data sub-carriers, pilot carriers, and a DC sub-carrier. The zero pad block changes the size of the input matrix from N-by-1 to K-by-1, where $N < K$, by truncating along the rows so that the total number of samples fed to the IFFT block are of a power of 2 as is required. The IFFT block is responsible for the frequency domain to time domain conversion of the input signal accompanied by the cyclic prefix block which is used to add cyclic prefix to the data.

3.1.2. OFDM Receiver

The OFDM receiver performs the exact reverse operation as the OFDM transmitter. The SIMULINK model of OFDM receiver is as shown in Figure 5. The reverse process of the OFDM transmitter takes place in the receiver.

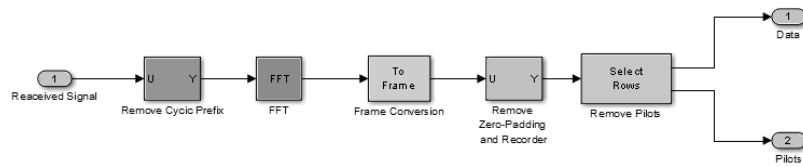


Figure 5: OFDM Receiver SIMULINK Model

3.2. OFDM-MIMO Proposed Model

The proposed SIMULINK model of OFDM-MIMO is as shown in Figure 6 below. The basic idea of OFDM-MIMO is to improve the data rate (bits/sec) and/or quality (BER) by using multiple antennas in the transmitter and receiver of the communication system. The MIMO system employs spatial diversity and uses Orthogonal Space Time Block Coding (OSTBC) as the core scheme[7-9].

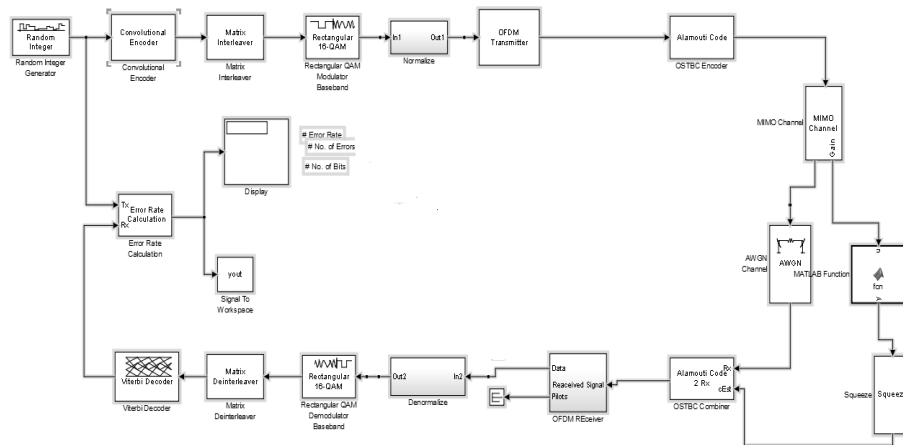


Figure 6: Proposed Model of OFDM-MIMO

IV. SIMULATION RESULTS AND ANALYSIS

Based on the IEEE 802.11 standards for implementation of Wireless Local Area Network (WLAN) communication, the numerical values set for the OFDM parameters are as shown in Table 1.

Table 1: Simulation Parameters

Parameter	Value
Standard	IEEE 802.11n
Sampling Rate $F_s = 1/T$	20 MHz
Symbol Interval T_s	$4.0 * 10^{-6}$ s
Convolutional Coding Rate	3/4
Modulation	16-QAM
Number Of Data Sub-Carriers N_{SD}	48
Number of Pilot Sub-Carriers N_{SP}	4
Total Number Of Sub-Carriers N_{ST}	52
Channel Model	AWGN and Rayleigh

The simulation results are presented in the form of curves of Bit Error Rate (BER) over numerous values of signal-to-noise ratio (SNR).

The Figure 7 presents the variations of the BER as function of SNR if the modulation is 16-QAM and for different number of transmit and receive antennas. The channel is AWGN and Rayleigh with two different sets of discrete path

delays. The first set takes into account maximum delay spread of $1\mu\text{s}$ (two taps) while the second set takes into account maximum delay spread of $5\mu\text{s}$ (six taps), as shown in the Figure by corresponding curves respectively. The Figure shows that as the maximum delay spread and the number of taps for outdoor WLAN increases the BER gradually increases for 2x2 configuration but on increasing the number of antennas at the transmitter and receiver side, for 3x3 and 4x4 antenna configuration, the BER decreases irrespective of the increase in the maximum delay spread and the number of taps. This proves the powerful performance enhancing capabilities of MIMO.

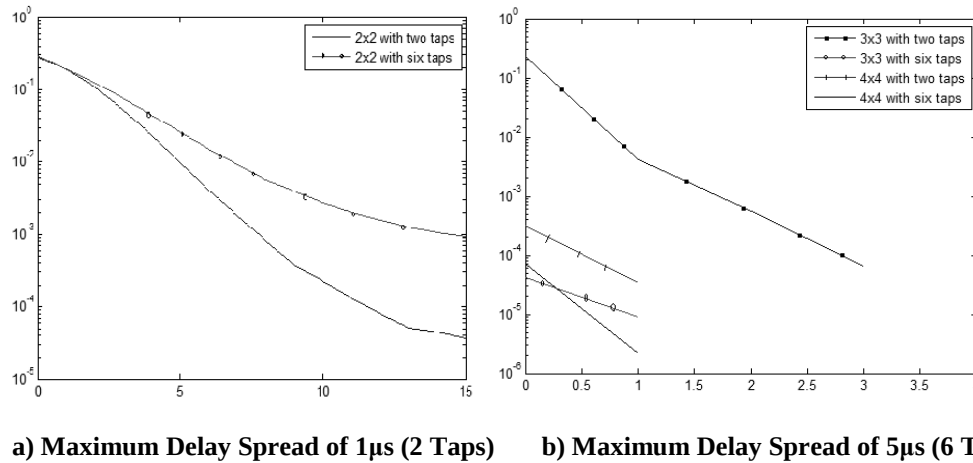


Figure 7: BER Vs SNR for Different Antenna Configuration and Maximum Delay Spread

The Figure 8 presents the system performance if the modulation is 16-QAM and for different antenna configurations. The channel is AWGN and frequency-selective Rayleigh with a set of discrete path delays that takes into account a maximum delay spread of $10\mu\text{s}$ (Eleven taps). In general, the system performance is better as we increase the number of transmission and/or reception antennas. The bit error rate is equal to 0.1019 for 2X2 OFDM-MIMO system, 0.0005928 for 3X3 OFDM-MIMO system and decreases to 0.00001611 for 4x4 OFDM-MIMO systems at a value of signal to noise ratio that is equal to 4. On increasing the value of the SNR, we notice a significant decrease in the BER. We have extracted the BER for different antenna configurations and saw that the performance for 4x4 antenna configuration of OFDM-MIMO system with maximum tolerable delay spread of $10\mu\text{s}$ (11 taps) exceeded the performance of all the other shown configurations.

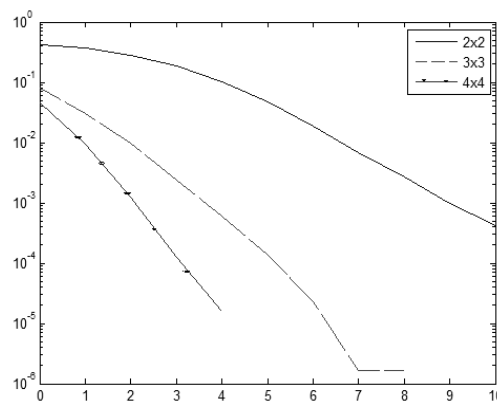


Figure 8: BER Vs SNR for Different Antenna Configurations with Maximum Delay Spread of $10\mu\text{s}$ (11 Taps)

V. CONCLUSIONS

In this paper, we have presented the performance analysis of a simple OFDM-MIMO system based on the 802.11n amendment and simulated it by using SIMULINK in MATLAB. The experimental results are carried out by using AWGN and frequency-selective Rayleigh channel with different sets of discrete path delays and different number of taps for different maximum tolerable delay spreads, and with 16-QAM modulation technique under $\frac{1}{2}$ OSTBC code rate. Furthermore simulations show that the 4x4 antenna configuration with $\frac{1}{2}$ OSTBC code rate have a performance gain when it is compared with a 3x3 model using OSTBC code rate $\frac{1}{2}$ and 2x2 model using OSTBC code rate 1. As shown by the numerical results the OFDM-MIMO systems have good performance when there are more antennas and the other conditions are same.

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